19-2048; Rev 0; 4/01

Low-Cost, SC70, Voltage-Output, High-Side Current-Sense Amplifier

MAX4073T/F/H

General Description

The MAX4073 low-cost, high-side current-sense amplifier features a voltage output that eliminates the need for gain-setting resistors making it ideal for cell phones, notebook computers, PDAs, and other systems where current monitoring is crucial. High-side current monitoring does not interfere with the ground path of the battery charger making the MAX4073 particularly useful in battery-powered systems. The input common-mode range of +2V to +28V is independent of the supply voltage. The MAX4073's wide 1.8MHz bandwidth makes it suitable for use inside battery-charger control loops.

The combination of three gain versions and a selectable external-sense resistor sets the full-scale current reading. The MAX4073 offers a high level of integration, resulting in a simple and compact current-sense solution.

The MAX4073 operates from a +3V to +28V single supply and draws only 0.5mA of supply current. This device is specified over the automotive operating temperature range (-40°C to +125°C) and is available in a space-saving 5-pin SC70 package (half the size of the SOT23).

For a similar device in a 6-pin SOT23 with a wider common-mode voltage range (0 to +28V), see the MAX4173 data sheet.

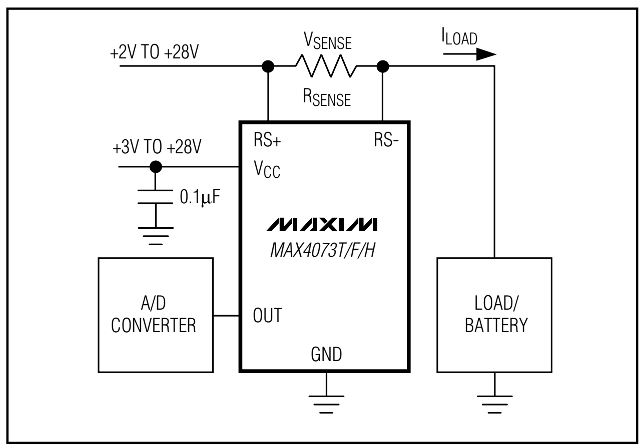
Applications

- Cell Phones
- Notebook Computers
- Portable/Battery-Powered Systems
- Smart Battery Packs/Chargers
- PDAs
- Power Management Systems
- PA Bias Control
- General System/Board-Level Current Monitoring
- Precision Current Sources

Features

- ♦ Low-Cost, Compact, Current-Sense Solution
- ♦ Three Gain Versions Available
  - +20V/V (MAX4073T)
  - +50V/V (MAX4073F)
  - +100V/V (MAX4073H)
- ♦ ±1.0% Full-Scale Accuracy
- ♦ 500µA Supply Current
- ♦ Wide 1.8MHz Bandwidth
- ♦ +3V to +28V Operating Supply
- ♦ Wide +2V to +28V Common-Mode Range Independent of Supply Voltage
- ♦ Automotive Temperature Range (-40°C to +125°C)
- ♦ Available in Space-Saving 5-Pin SC70 Package

Typical Operating Circuit



Pin Configurations appear at end of data sheet.

Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE	GAIN (V/V)	TOP MARK
MAX4073TAXK-T	-40°C to +125°C	5 SC70-5	20	ACM
MAX4073TAUT-T	-40°C to +125°C	6 SOT23-6	20	AAUE
MAX4073FAXK-T	-40°C to +125°C	5 SC70-5	50	ACN
MAX4073FAUT-T	-40°C to +125°C	6 SOT23-6	50	AAUF
MAX4073HAXK-T	-40°C to +125°C	5 SC70-5	100	ACO
MAX4073HAUT-T	-40°C to +125°C	6 SOT23-6	100	AAUG

ABSOLUTE MAXIMUM RATINGS

V_{CC} to GND ....-0.3V to +30V
RS+, RS- to GND ....-0.3V to +30V
OUT to GND ....-0.3V to (V_{CC} + 0.3V)
Output Short-Circuit to GND ....Continuous
Differential Input Voltage (V_{RS+} - V_{RS-}) ....±5V
Current Into Any Pin...±20mA
Continuous Power Dissipation (T_A = +70°C)
  5-pin SC70 (derate 2.27mW/°C above +70°C)............200mW
  6-pin SOT23 (derate 8.7mW/°C above +70°C)............696mW
Operating Temperature Range ....-40°C to +125°C
Junction Temperature...+150°C
Storage Temperature Range ....-65°C to +150°C
Lead Temperature (soldering, 10s) ....+300°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS

(V_{RS+} = +2V to +28V, V_{SENSE} = (V_{RS+} - V_{RS-}) = 0, V_{CC} = +3V to +28V, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Operating Voltage Range	V_{CC}	(Note 2)	3		28	V
Common-Mode Input Range	V_{CMR}	(Note 3)	2		28	V
Common-Mode Rejection	CMR	V_{SENSE} = 100mV, V_{CC} = 12V		90		dB
Supply Current	I_{CC}	V_{CC} = 28V		0.5	1.2	mA
Leakage Current	I_{RS+}/I_{RS-}	V_{CC} = 0, V_{RS+} = 28V		0.05	1	µA
Input Bias Current	I_{RS+}			20	60	µA
	I_{RS-}			40	120	
Full-Scale Sense Voltage	V_{SENSE}	V_{SENSE} = (V_{RS+} - V_{RS-})		150		mV
Total OUT Voltage Error (Note 4)		V_{SENSE} = 100mV, V_{CC} = 12V, V_{RS+} = 2V		±1.0		%
		V_{SENSE} = 100mV, V_{CC} = 12V, V_{RS+} = 12V, T_A = +25°C		±1.0	±5.0	
		V_{SENSE} = 100mV, V_{CC} = 12V, V_{RS+} = 12V, T_A = T_{MIN} to T_{MAX}			±7.0	
		V_{SENSE} = 100mV, V_{CC} = 28V, V_{RS+} = 28V, T_A = +25°C		±1.0	±5.0	
		V_{SENSE} = 100mV, V_{CC} = 28V, V_{RS+} = 28V, T_A = T_{MIN} to T_{MAX}			±8.5	
		V_{SENSE} = 6.25mV (Note 5); V_{CC} = 12V, V_{RS+} = 12V		±7.5		
Extrapolated Input Offset Voltage	V_{OS}	V_{CC} = V_{RS+} = 12V, V_{SENSE} > 10mV		1.0		mV
OUT High Voltage	(V_{CC} - V_{OH})	V_{SENSE} = 150mV: MAX4073T, V_{CC} = 3V		0.8	1.2	V
		V_{SENSE} = 150mV: MAX4073F, V_{CC} = 7.5V				
		V_{SENSE} = 150mV: MAX4073H, V_{CC} = 15V				

ELECTRICAL CHARACTERISTICS (continued)

(V_{RS+} = +2V to +28V, V_{SENSE} = (V_{RS+} - V_{RS-}) = 0, V_{CC} = +3V to +28V, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Bandwidth	BW	V_{CC} = 12V, V_{RS+} = 12V, C_{LOAD} = 5pF	MAX4073T, V_{SENSE} = 100mV		1.8		MHz
			MAX4073F, V_{SENSE} = 100mV		1.7		
			MAX4073H, V_{SENSE} = 100mV		1.6		
			MAX4073T/F/H V_{SENSE} = 6.25mV (Note 5)		600		kHz
Gain	A_V	MAX4073T			20		V/V
		MAX4073F			50		
		MAX4073H			100		
Gain Accuracy	ΔA_V	V_{CC} = 12V, V_{RS+} = 12V, V_{SENSE} = 10mV to 150mV, MAX4073T/F	T_A = +25°C		±1.0	±4.5	%
			T_A = T_{MIN} to T_{MAX}			±6.5	
		V_{CC} = 12V, V_{RS+} = 12V, V_{SENSE} = 10mV to 100mV, MAX4073H	T_A = +25°C		±1.0	±4.5	
			T_A = T_{MIN} to T_{MAX}			±6.5	
OUT Settling Time to 1% of Final Value		V_{CC} = 12V V_{RS+} = 12V C_{LOAD} = 5pF	V_{SENSE} = 6.25mV to 100mV		400		ns
			V_{SENSE} = 100mV to 6.25mV		800		
Output Resistance	R_{OUT}				12		kΩ
Power-Supply Rejection Ratio	PSRR	V_{CC} = 3V to 28V	V_{SENSE} = 60mV, MAX4073T	70	78		dB
			V_{SENSE} = 24mV, MAX4073F	70	85		
			V_{SENSE} = 12mV, MAX4073H	70	90		
Power-Up Time (Note 6)		C_{LOAD} = 5pF, V_{SENSE} = 100mV			5		µs
Saturation Recovery Time (Note 7)		V_{CC} = 12V, V_{RS+} = 12V, C_{LOAD} = 5pF			5		µs

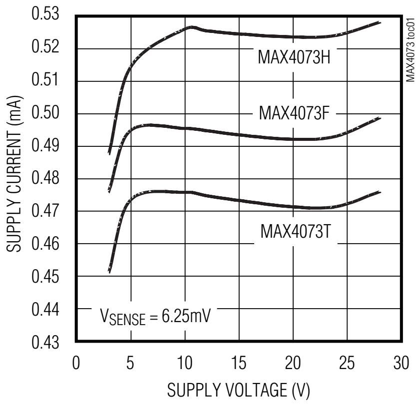
Note 1: All devices are 100% production tested at T_A = +25°C. All temperature limits are guaranteed by design.
Note 2: Inferred from PSRR test.
Note 3: Inferred from OUT Voltage Error test.
Note 4: Total OUT Voltage Error is the sum of the gain and offset errors.
Note 5: 6.25mV = 1/16 of 100mV full-scale sense voltage.
Note 6: Output settles to within 1% of final value.
Note 7: The device will not experience phase reversal when overdriven.

Low-Cost, SC70, Voltage-Output, High-Side Current-Sense Amplifier

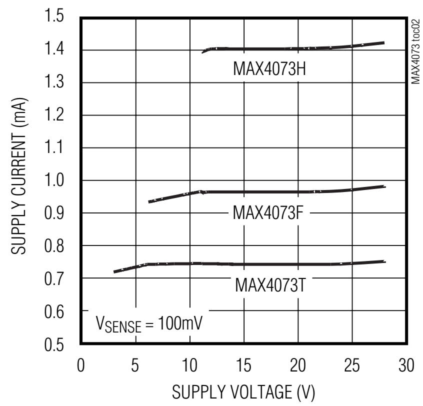
Typical Operating Characteristics

(V_{CC} = +12V, V_{RS+} = +12V, V_{SENSE} = 100mV, C_L = 5pF, T_A = +25°C, unless otherwise noted.)

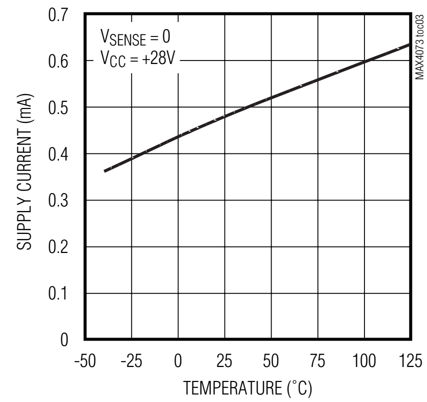
SUPPLY CURRENT vs. SUPPLY VOLTAGE



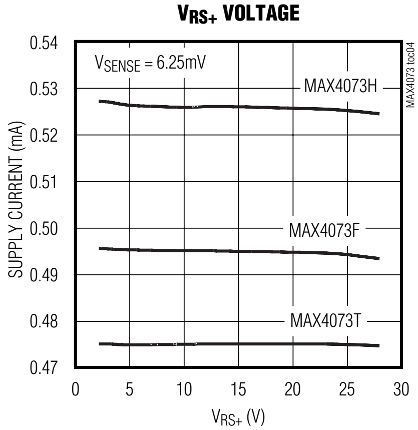
SUPPLY CURRENT vs. SUPPLY VOLTAGE



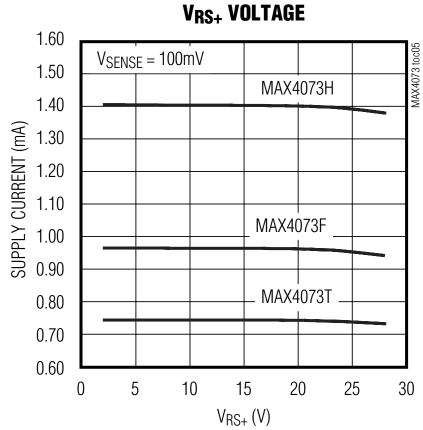
SUPPLY CURRENT vs. TEMPERATURE



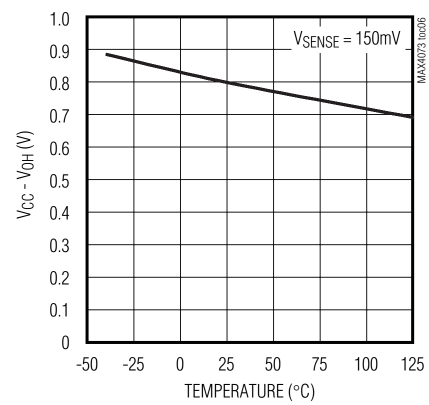
SUPPLY CURRENT vs. V_{RS+} VOLTAGE



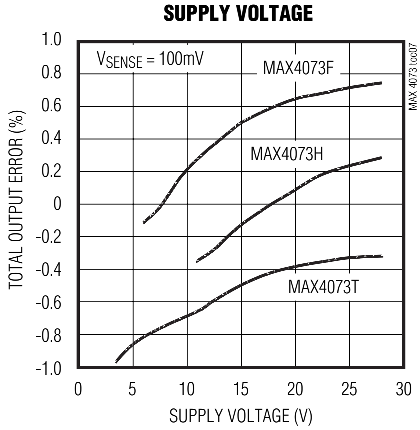
SUPPLY CURRENT vs. V_{RS+} VOLTAGE



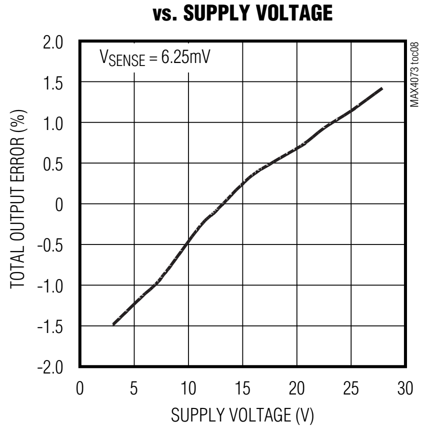
OUTPUT HIGH VOLTAGE (V_{CC} - V_{OH}) vs. TEMPERATURE



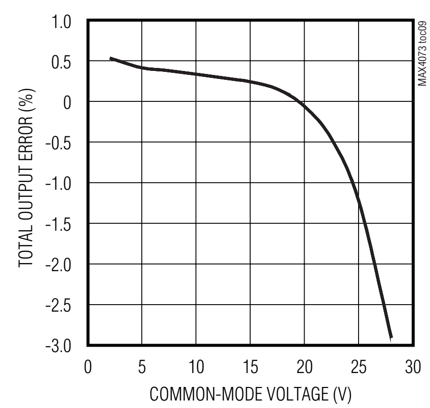
TOTAL OUTPUT ERROR vs. SUPPLY VOLTAGE



TOTAL OUTPUT ERROR vs. SUPPLY VOLTAGE



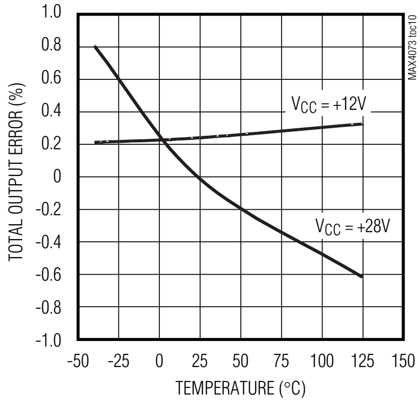
TOTAL OUTPUT ERROR vs. COMMON-MODE VOLTAGE



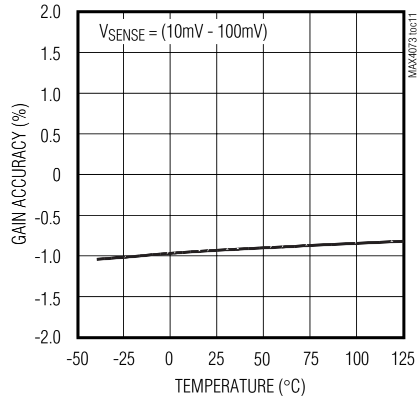
Typical Operating Characteristics (continued)

(V_{CC} = +12V, V_{RS+} = +12V, V_{SENSE} = 100mV, C_L = 5pF, T_A = +25°C, unless otherwise noted.)

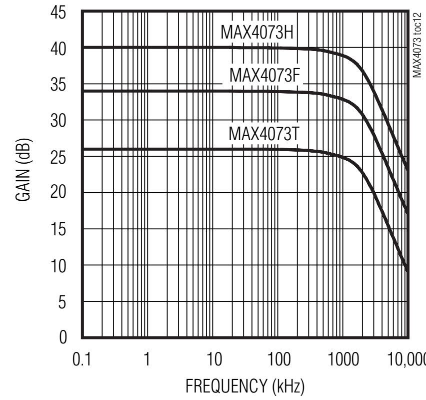
TOTAL OUTPUT ERROR vs. TEMPERATURE



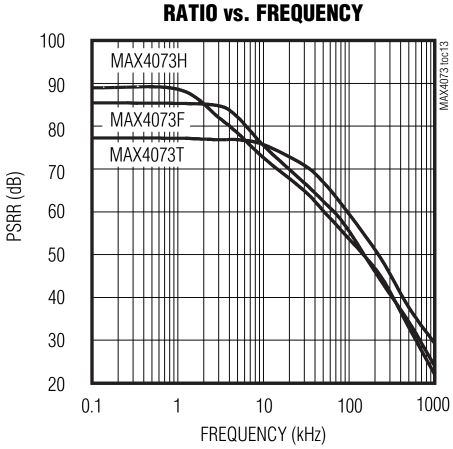
GAIN ACCURACY vs. TEMPERATURE



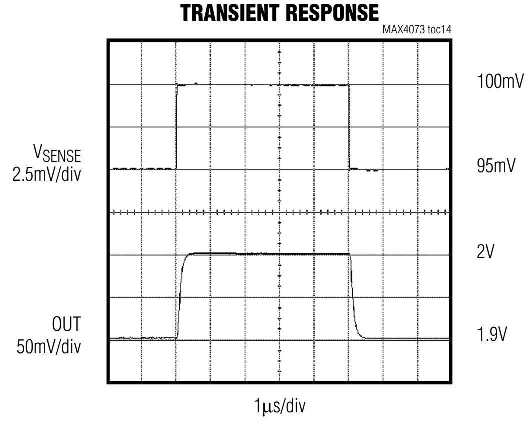
SMALL-SIGNAL GAIN vs. FREQUENCY



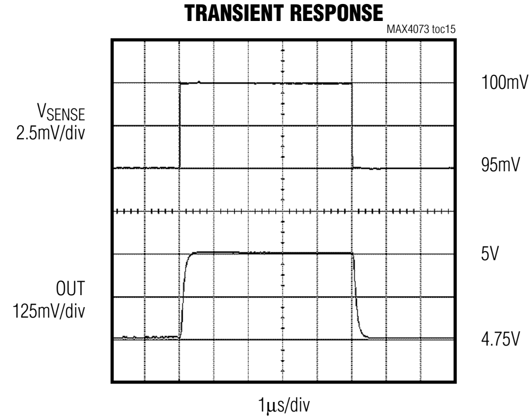
POWER-SUPPLY REJECTION RATIO vs. FREQUENCY



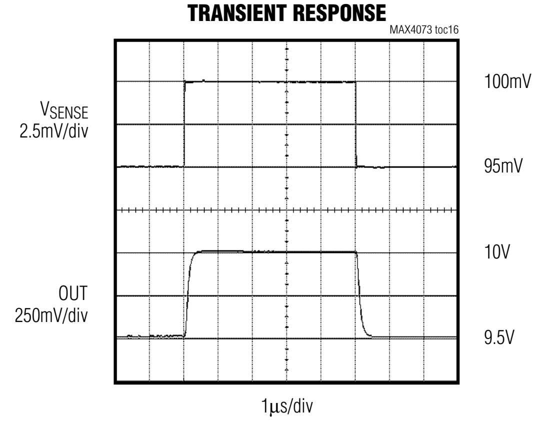
MAX4073T SMALL-SIGNAL TRANSIENT RESPONSE



MAX4073F SMALL-SIGNAL TRANSIENT RESPONSE



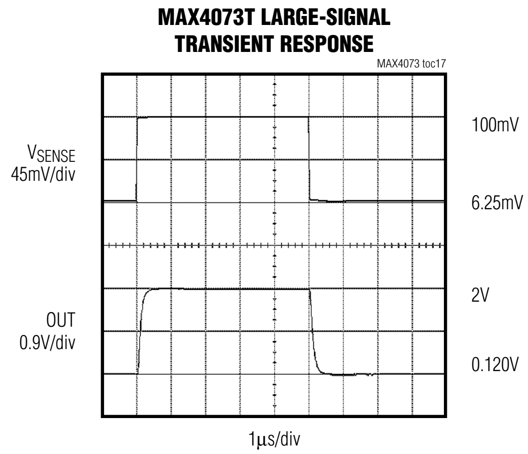
MAX4073H SMALL-SIGNAL TRANSIENT RESPONSE

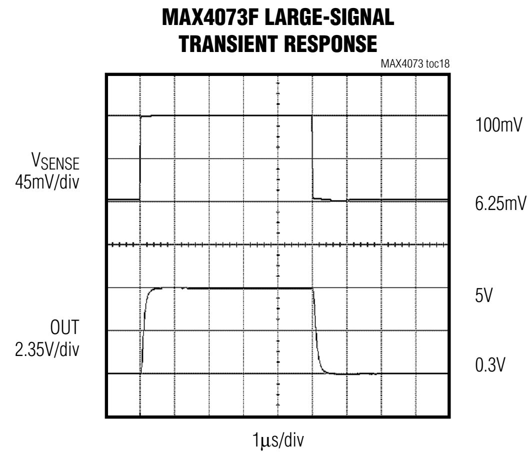


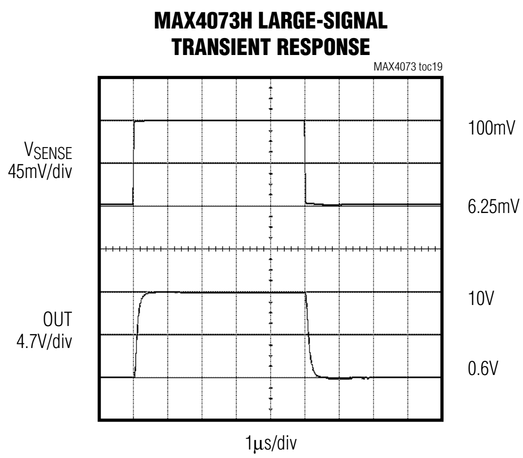
Low-Cost, SC70, Voltage-Output, High-Side Current-Sense Amplifier

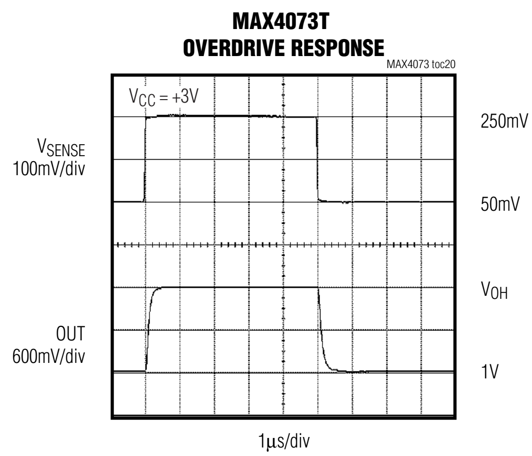
Typical Operating Characteristics (continued)

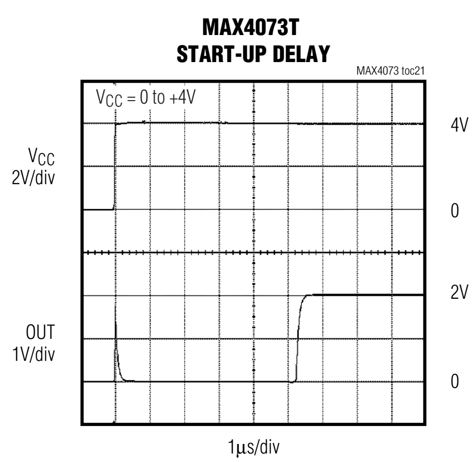
(V_{CC} = +12V, V_{RS+} = +12V, V_{SENSE} = 100mV, C_L = 5pF, T_A = +25°C, unless otherwise noted.)











Pin Description

PIN		NAME	FUNCTION
SOT23-6	SC70-5		
1, 2	2	GND	Ground
3	3	V_{CC}	Supply Voltage Input. Bypass to GND with a 0.1µF capacitor.
4	4	RS+	Power-Side Connection to the External Sense Resistor
5	5	RS-	Load-Side Connection to the External Sense Resistor
6	1	OUT	Voltage Output. V_{OUT} is proportional to V_{SENSE}. Output impedance is approximately 12kΩ.

Detailed Description

The MAX4073 high-side current-sense amplifier features a +2V to +28V input common-mode range that is independent of supply voltage. This feature allows the monitoring of current out of a battery as low as +2V and also enables high-side current sensing at voltages greater than the supply voltage (V_{CC}).

The MAX4073 operates as follows: current from the source flows through R_{SENSE} to the load (Figure 1). Since the internal-sense amplifier's inverting input has high impedance, negligible current flows through RG2 (neglecting the input bias current). Therefore, the sense amplifier's inverting-input voltage equals V_{SOURCE} - (I_{LOAD})(R_{SENSE}). The amplifier's open-loop gain forces its noninverting input to the same voltage as the inverting input. Therefore, the drop across RG1 equals (I_{LOAD})(R_{SENSE}). Since I_{RG1} flows through RG1, I_{RG1} = (I_{LOAD})(R_{SENSE}) / RG1. The internal current mirror multiplies I_{RG1} by a current gain factor, β, to give $I_{RGD} = \beta \times I_{RG1}$. Solving $I_{RGD} = \beta \times (I_{LOAD})(R_{SENSE})$ / RG1. Assuming infinite output impedance, V_{OUT} = (I_{RGD})(RGD). Substituting in for I_{RGD} and rearranging, $V_{OUT} = \beta \times (RGD / RG1)(R_{SENSE} \times I_{LOAD})$. The parts gain equals β × RGD / RG1. Therefore, V_{OUT} = (GAIN) (R_{SENSE}) (I_{LOAD}), where GAIN = 20V/V for MAX4073T, GAIN = 50V/V for MAX4073F, and GAIN = 100V/V for MAX4073H.

Set the full-scale output range by selecting R_{SENSE} and the appropriate gain version of the MAX4073.

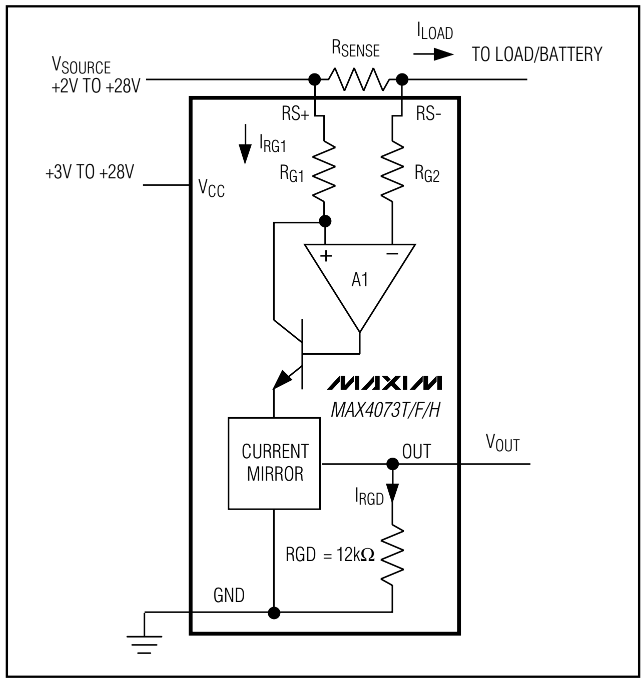


Figure 1. Functional Diagram

Applications Information

Recommended Component Values

The MAX4073 senses a wide variety of currents with different sense resistor values. Table 1 lists common resistor values for typical operation of the MAX4073.

Choosing R_{SENSE}

To measure lower currents more accurately, use a large value for R_{SENSE}. The larger value develops a higher-sense voltage that reduces offset voltage errors of the internal op amp. Typical sense voltages range between 10mV and 150mV.

In applications monitoring very high currents, R_{SENSE} must be able to dissipate the I^2R losses. If the resistor's rated power dissipation is exceeded, its value may drift or it may fail altogether, causing a differential voltage across the terminals in excess of the absolute maximum ratings (±5V).

If I_{SENSE} has a large high-frequency component, minimize the inductance of R_{SENSE}. Wire-wound resistors have the highest inductance, metal-film resistors are somewhat better, and low-inductance metal-film resistors are best suited for these applications.

For V_{SENSE} = 100mV, full-scale output voltage can be 2V, 5V, or 10V depending on the gain. For proper operation, ensure V_{CC} exceeds the full-scale output voltage by 1.2V (see Output High Voltage (V_{CC} - V_{OH}) vs. Temperature in the *Typical Operating Characteristics*).

Using a PCB Trace as R_{SENSE}

If the cost of R_{SENSE} is an issue and accuracy is not critical, use the alternative solution shown in Figure 2. This solution uses copper PC board traces to create a sense resistor. The resistivity of a 0.1-inch-wide trace of 2-ounce copper is approximately 30mΩ/ft. The resistance-temperature coefficient of copper is fairly high (approximately 0.4%/°C), so systems that experience a wide temperature variance must compensate for this effect. In addition, do not exceed the maximum power dissipation of the copper trace.

For example, the MAX4073T (with a maximum load current of 10A and an R_{SENSE} of 5mΩ) creates a full-scale V_{SENSE} of 50mV that yields a maximum V_{OUT} of 1V. R_{SENSE} in this case requires about 2 inches of 0.1 inch-wide copper trace.

Output Impedance

The output of the MAX4073 is a current source driving a 12kΩ resistance. Resistive loading added to OUT reduces the output gain of the MAX4073. To minimize output errors for most applications, connect OUT to a high-impedance input stage. When output buffering is required, choose an op amp with a common-mode input range and an output voltage swing that includes ground when operating with a single supply. The op amp's supply voltage range should be at least as high as any voltage the system may encounter.

The percent error introduced by output loading is determined with the following formula:

$$\%_{ERROR} = 100\left(\frac{R_{LOAD}}{12k\Omega + R_{LOAD}} - 1\right)$$

where R_{LOAD} is the external load applied to OUT.

Current Source Circuit

Figure 3 shows a block diagram using the MAX4073 with a switching regulator to make a current source.

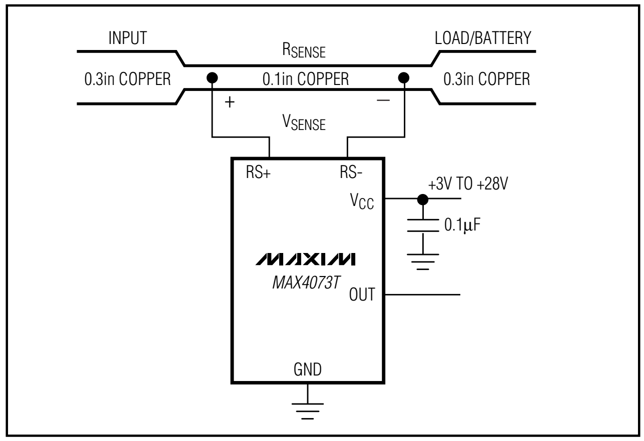


Figure 2. MAX4073T Connections Showing Use of PC Board

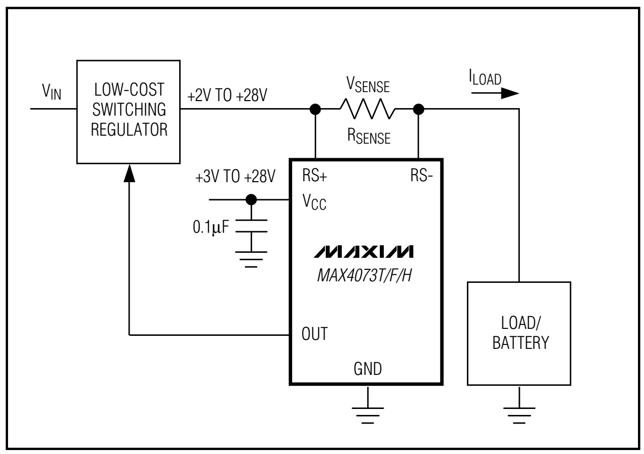
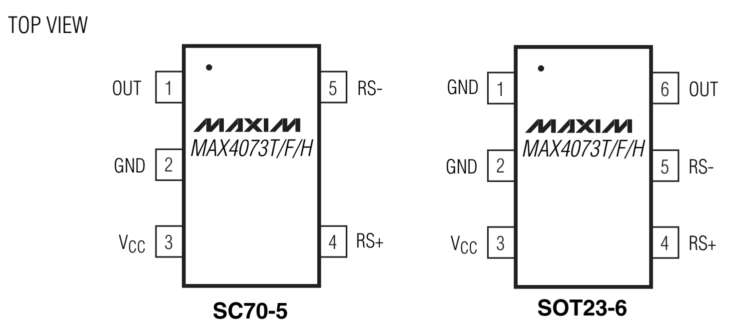


Figure 3. Current Source

Table 1. Recommended Component Values

FULL-SCALE LOAD CURRENT I_{LOAD} (A)	CURRENT-SENSE RESISTOR R_{SENSE} (mΩ)	GAIN	FULL-SCALE OUTPUT VOLTAGE (FULL-SCALE V_{SENSE} = 100mV) V_{OUT} (V)
0.1	1000	20	2.0
		50	5.0
		100	10.0
1	100	20	2.0
		50	5.0
		100	10.0
5	20	20	2.0
		50	5.0
		100	10.0
10	10	20	2.0
		50	5.0
		100	10.0

Pin Configurations



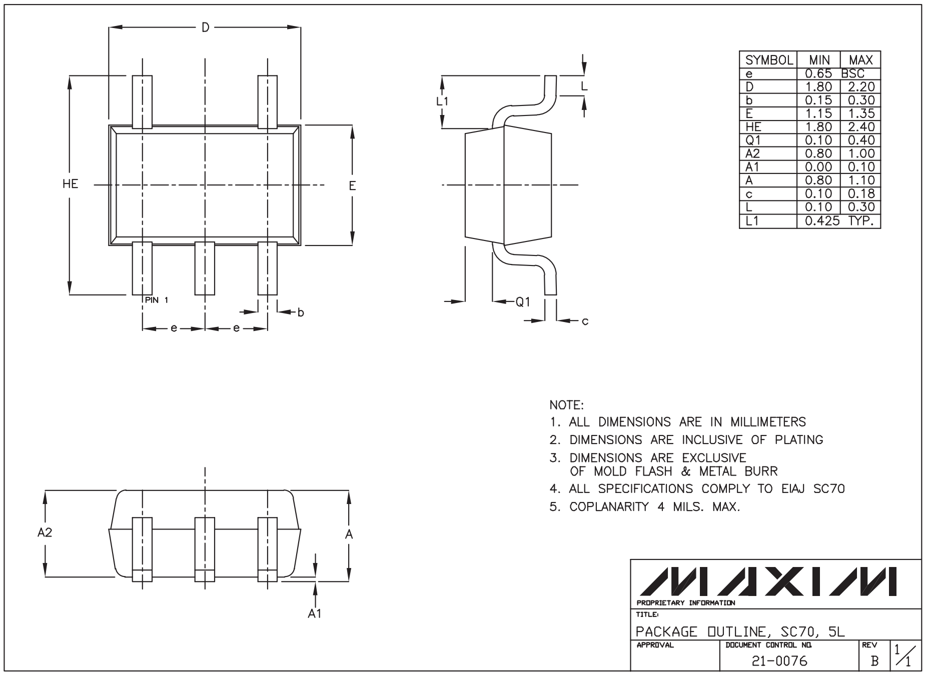
Chip Information

TRANSISTOR COUNT: 187

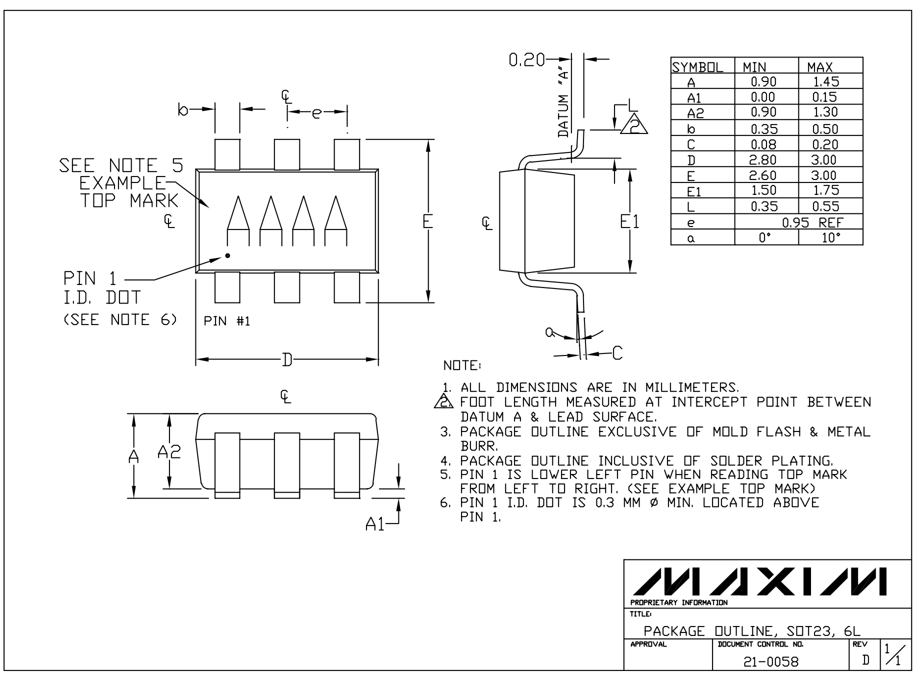
PROCESS: Bipolar

Low-Cost, SC70, Voltage-Output, High-Side Current-Sense Amplifier

Package Information



SYMBOL	MIN	MAX
e	0.65 BSC	
D	1.80	2.20
b	0.15	0.30
E	1.15	1.35
HE	1.80	2.40
Q1	0.10	0.40
A2	0.80	1.00
A1	0.00	0.10
A	0.80	1.10
c	0.10	0.18
L	0.10	0.30
L1	0.425 TYP.	



SYMBOL	MIN	MAX
A	0.90	1.45
A1	0.00	0.15
A2	0.90	1.30
b	0.35	0.50
C	0.08	0.20
D	2.80	3.00
E	2.60	3.00
E1	1.50	1.75
L	0.35	0.55
e	0.95 REF	
α	0°	10°